Kennecott
Utah Copper

EPA Mine Waste Regulatory Development

Work Group - Tour

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COPPER PRODUCTION AND ASSOCIATED MATERIAL MANAGEMENT
AT AN INTEGRATED FACILITY: UTAH COPPER

Introduction

This report summarizes salient aspects of materials management at Kennecott's integrated copper production facility located 25 miles south west of Salt Lake City, Utah. It focuses on approaches to maximize resource recovery and upon waste management techniques at a modern integrated copper production facility. Where appropriate, national data are included for comparison purposes. Photographs, figures, and tables are included at the end of the report.

Background, The Bingham Mine

Table 1 shows a chronology of milestones of Kennecott's Utah Copper facility. Mining began at the Bingham mine in 1905. Originally, the workings were underground, but by 1906 open pit mining began and soon accounted for nearly all ore production. The Bingham mine was the first to develop porphyry copper deposits--large relatively uniformly disseminated low-grade copper ores. Prior to that time copper ore was mined selectively from vein type deposits containing relatively large percentages of copper. Daniel Jackling and others reckoned that porphyry deposits could be mined profitably if done on a large enough scale.[1/] Today, the majority of

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1/ This insight was by no means universally shared at the time. According to Parsons (Parsons, A.B., The Porphyry Coppers, AIME, New York 1953, pp. 5 *et seq.*), Richard P. Rothwell, the editor of the influential Mining and Engineering Journal, commented derisively on an 1899 report on the Utah orebody by Thomas Wier, included in a stock prospectus to British investors as follows,

> "Mr. Wier's assumptions are certainly on an exceedingly liberal scale, and it may well be questioned whether a good deal more development work is not needed to prove the existence of so great a mass of ore. But even if we accept the statement and admit that the company has a very large body of low-grade ore, it does not seem to better the case.****Even if the greater part--or even the whole--should reach 2 per cent, it would not better the situation. It would be impossible to mine and treat ores carrying 2 per cent or less of copper under existing conditions in Utah.
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> In the Montana mines [he alludes to Butte, of course] where ores from 4 per cent up are treated, it is well known that the profits come chiefly from the gold and silver in the ores; and it is not claimed that the Boston Consolidated mineral [forerunner of Kennecott] has more than very small values in gold and silver; and many other parallel cases might be presented. Allowing for the greatest cheapness of mining, which can be made possible by the large size of the orebody, one cannot figure out anything but a heavy loss on 1.5 and 2 per cent copper ore. Moreover, it is not probable that the price of copper is going to stay permanently at 17 or 18c.; and with every fall the loss on operations would be greater.

copper reserves and production comes from porphyry ores (see Table 2) and, in the United States, over 90% from surface or open pit operations.[2/]

As noted, the economic viability of mining porphyry ores capitalizes upon economies of scale in materials handling. Porphyry mines are among the world's largest; the Bingham mine (shown in photograph 1) in particular, is the world's largest man-made excavation:

(i) The 1,900 acre open pit measures 2.3 miles wide at the top and is over 1/2 mile deep.

(ii) Over 4.8 billion short tons of ore, metal-bearing flux, and overburden have been removed since startup (eight times the amount of earth moved in the original digging of the Panama Canal).[3/]

(iii) As of 1 January 1987, 1,642 million tons of ore have been mined and processed, yielding 12.7 million tons of copper metal.

(iv) To make this ore available, 3,205 million tons of overburden have been removed to mine dumps (where much of it is leached).

(v) Finally, in addition to copper, 853 million pounds of molybdenum (in various forms) and significant quantities of gold and silver have been produced. Incidentally, as a result of Clean Air Act mandates to reduce sulfur dioxide (SO_2) emissions from the smelter, sulfuric acid (H_2SO_4) is now produced in greater quantities than copper.[4/]

1/ Continued

On the company's own showing, therefore, the more ore it has of the kind it claims, the poorer it is. Undoubtedly, our London friends who are buying the stock at high prices will realize this a little later."

Rothwell was proven dramatically wrong in short order.

2/ U.S. Department of the Interior, bureau of Mines, Minerals Yearbook, Various Years.

3/ Arrington, L.J., and Hansen, G.B., "The Richest Hole on Earth; A History of the Bingham Copper Mine, Utah State University Press, Logan, Utah, 1963, p.7.

4/ SO_2 is produced in the smelting process (discussed later in the main text) from sulfur containing copper ores (e.g. chalcopyrite, bornite, and chalcocite see Table 3), and other sulfur containing materials found with these ores.

Overview of the Copper Production Process

Figure 1 presents a simplified diagram of the copper production process used at Kennecott's Utah facility, and Figure 2 adds current production quantities for this facility after the current $400 million modernization program is complete.

In brief, the production process consists of four steps all of which take place in Kennecott's integrated Utah facility:

(i) Mining, where ore[5] and overburden ore removed from the pit and segregated. The overburden is placed in dumps such as are shown in Photograph 2, and the ore is transported to a concentrator for subsequent processing. Some of the ore is suitable for leaching (a leach dump is shown in Photograph 3) and recovery in a precipitation plant (shown in Photograph 4 and diagrammed in Figure 3), discussed below.

(ii) Concentrating, (Also termed beneficiation) where the ore is crushed, ground, and separated from by-products and waste by a process termed froth flotation. Photograph 5 shows the new Kennecott concentrator under construction. The waste material, called tailings, is sent to a 5,600 acre tailings pond (shown in Photograph 6) for disposal, and the copper-rich concentrate (containing about 27% copper) is sent to a smelter for pyrometallurgical treatment.

(iii) Smelting, (Also termed processing) here using a Noranda reactor and Peirce-Smith converters (shown in Photograph 7) where sulfur, iron, and other impurities are removed to produce copper anodes (shown in Photograph 8) for electrolytic refining, and

(iv) Refining, (Also termed processing) where the anodes are purified electrolytically (see Photograph 9) to produce 99.9% pure copper cathodes for shipment to semi-fabricators, and refinery slimes for precious metals recovery at a co-located precious metals refinery.

Ore Grades and Stripping Ratios: A Key Perspective

Before discussing relevant aspects of each of the stages in primary copper production it is important to address the significance of ore grades and stripping ratios as they relate to the mine waste issue.

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[5] Both "ore" and "overburden" contain copper. The mineral economist's definition of ore is "material that can be mined and processed at a profit." Thus, only material above a certain grade--termed the "cutoff" grade of copper is termed ore. Under present economics the cutoff grade is approximately 0.45% copper. In earlier years, when inflation-adjusted copper prices were higher, the cutoff grade was lower (0.35%). Material containing less than the cutoff grade is termed overburden, although it may be profitable to leach some of this material. In fact at Utah 75% of the overburden is part of the leach recovery system.

Ore grade means the quantity of metal (copper in this case) in the ore being mined. Copper ore mined in the United States and, after concentration (if required), shipped directly to smelters in recent years has averaged less than 0.6% copper. In 1984, for example, the recoverable copper content of domestic copper ores was only 0.52%[6/] equivalent to a yield of approximately 10.5 pounds of copper per ton of ore. Highly efficient materials handling, separation, and processing technologies employed by the domestic copper industry enable such "lean" or low grade ore to be mined profitably.

The second important term is "stripping ratio." In the context of an open pit operation, it means the quantity of overburden removed per unit of ore produced. Because of the geometry of the orebody, some overburden must be removed to provide access to the ore. The stripping ratio is a function of the orebody geometry, the mining plan, and, of course, economic factors (more specifically the ratio of stripping and placement costs to net ore values).

Stripping ratios also vary with type of ore being mined and the mining method (e.g., surface or open pit versus underground). Stripping ratios for domestic copper mines since 1960 are shown in Table 4 as taken from U.S. Bureau of Mines (USBM) data. As can be seen, stripping ratios for domestic open pit copper mines have averaged more than 2.0 in recent years.

It is also important to note that, on average, the grade of domestic copper ores being mined has decreased over the years, as is shown in Figure 4 (also Table 5) for the Bingham mine. This trend reflects two phenomena:

(i) the gradual exhaustion of the highest grade portions of the ore bodies, and

(ii) increased mining efficiency which has enabled progressively leaner materials to be mined at a profit.[7/]

The above discussion enables an understanding of the two key points relative to domestic copper mining:

(i) First, the combination of such low ore grades and high stripping ratios implies that the domestic copper mining industry must handle large quantities of material per unit of marketable product. Overall, approximately 600 tons of material (tailings, overburden) are generated per ton of refined copper produced. Figure 5 (see also Table 5)

6/ Jolly, J.L., and D.L. Edelstein, "Copper," chapter in Minerals Yearbook 1984, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1985, p. 320. The ore grade mined in many other countries (e.g., Chile) is higher than that mined in the United States.

7/ This notwithstanding the post 1980 downward spiral in copper prices which reached depression-era levels in real terms and therefore increased cutoff grades.

shows how the ratio of overburden and tailings to copper has varied with time at the Bingham mine. In recent years, this ratio has been in the range of 500 to 800! According to the latest mining plan, this ratio is expected to decrease slightly at the Bingham mine. But, notwithstanding this decrease, the ratio is orders-of-magnitude greater than that experienced by other domestic industries. These materials are not hazardous (in a RCRA context) but are large in quantity.

(ii) Second, the fact that the recoverable metal content is so low in comparison to the amount of material that has to be moved, places a premium on efficiency in the processing of copper ores. Yield and recovery improvements are extremely important, and the domestic copper industry is always seeking means to increase recovery. The economic importance of primary copper recovery is easily illustrated: at 34,6585,000 annual tons (the 1970-79 average for Bingham) ore throughput of average grade 0.65%, a 1% increase in recovery amounts to 2255 tons per year of copper, equivalent to approximately $3.4 million annually assuming a selling price of $0.75 per pound.

One major recovery improvement came about with the introduction of froth flotation to replace gravity separation in the ore concentrating process. In the early 1920s, when froth flotation was first introduced, concentrator recoveries (shown in Table 5) increased dramatically from approximately 60% to 80%, and by 1930 to values of 90% or more.

A second illustration of the attention devoted to recovery improvements was the introduction of baghouses and electrostatic precipitators on smelters to increase copper recovery by capturing copper-rich flue dusts--this long before the Clean Air Act was enacted into law.[8/]

The importance of maximizing recovery is relevant in a RCRA context for two reasons: First, this industry, unlike many others, already has a strong economic stake in resource conservation. Therefore it is unnecessary to seek regulatory incentives to achieve this same objective. Second, economic considerations dictate that many of the materials that might otherwise be thought of as wastes are, in fact, highly valuable process streams. Reactor (smelting) slag, for example, is a material that is separated from copper rich (71%) matte produced in the Noranda process used at Kennecott's Utah smelter. This slag averages approximately 7% copper[9/]

8/ Parsons, A.B., The Porphyry Coppers, AIME, New York 1933, pp 504 *et seq*.

9/ Not all reactor slags are as rich in copper and slags from some smelters

-- 13.5 times as rich as the copper ore itself. Other factors held constant, it is much more attractive to recover copper from a material that contains 7% copper than to mine and concentrate 0.52% ore. The copper ore benchmark makes it easy to understand why these slags are highly valuable and are returned to the reactor at the Kennecott facility.

As another example, treatment and recovery of by- or co-products of copper smelting and refining is often critical to the economics of copper production. Studies by USBM[10/] indicate that by-product credits have averaged 14 cents per pound of copper produced -- effecting a 16% reduction in the cost of domestic copper production over the years from 1981 to 1984. It is no exaggeration to claim that most domestic copper mines would not be economically viable were it not for by-product recovery credits. Refinery "slimes" are highly valuable feed materials for a precious metals refinery co-located with the Utah Copper refinery. National data for by- and co-products produced from copper ores for 1978 and 1982 are shown in Table 6A and 6B.[11/] As can be seen, an appreciable fraction of the domestic supply of several important materials -- including arsenic, rhenium, selenium, palladium, tellurium, silver, platinum, molybdenum, and gold -- is obtained from copper ores. In recent years, for example, more than one-third of domestic gold and silver output has been produced as a by- or co-product from copper ores.

A typical analysis of refining slimes produced at Kennecott's Utah facility is as follows: copper, 25%; gold, 150 ounces per ton; silver, 2200 ounces per ton; and recoverable quantities of selenium and tellurium.[12/] Such a material is very much "richer" than gold or silver ores now being mined (to say nothing of copper). For example, according to USBM,[13/] "the

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9/ Continued

are discarded or sold (see later discussion in text). This serves as an interesting illustration of the uniqueness of the mineral processing industries and the need for case-by-case analysis in a RCRA context. Although a common name, "slag," is employed, at some smelters slag is "copper-rich" and clearly a process material, and at other smelters is discarded.

10/ Jolly, J.L.W., "Copper," chapter in Mineral Facts and Problems, 1985 Edition, U.S. Department of the Interior, Bureau of Mines, bulletin 675, 1986, Washington, D.C., p. 212.

11/ Jolly, J.L.W., "Copper," chapter in Mineral Facts and Problems, 1985 Edition, U.S. Department of the Interior, bureau of Mines, Bulletin 675, 1986, Washington, D.C., p. 210. H.J. Schroeder and J.H. Jolly, "Copper," chapter in Mineral Facts and Problems, 1980 Edition, U.S. Department of the Interior, bureau of Mines, Bulletin 675, 1986, Washington, D.C., p. 236.

12/ Kennecott, "Utah Copper Division Refinery," report and accompanying flow sheets, undated.

13/ Lucas, J.M., "Gold," chapter in Minerals Yearbook 1984, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1985, p. 407.

average recovery grade of gold ores processed from lode mine sources was 0.06 ounce per short ton, while placer gravels yield an average of 0.007 ounce per cubic yard washed." (Emphasis added) The gold content of Kennecott's refinery slimes (150 ounces per ton) is 2,500 times greater than that of gold ores processed from lode mine sources.

Likewise, Kennecott refinery slimes have a much greater silver content than domestic silver ores being mined. In 1983, for example, approximately 30 million troy ounces of silver were recovered from 7.5 million short tons of silver ore,14/ a ratio of only 4 ounces per ton. Refinery slimes (assaying 2,200 ounces of silver per ton) contain 550 times as much silver as domestic silver ores.

The above examples show clearly why the term "waste" is inappropriate for most process streams at a copper processing facility. These remarks are appropriate because, at various times, EPA has used the term "waste" to characterize many process streams in the primary copper production. There is no logical basis for such characterization, a position clearly supported by the D.C. Circuit's recent opinion in AMC v. EPA, No. 85-1206 (July 31, 1987) which held that these reprocessed materials cannot be regulated as wastes under the Solid Waste Disposal Act. The court began its analysis by targeting primary metals production as an industry that produces a particularly wide array of valuable secondary materials:

> "Mining. In the mining industry, primary metals production involves the extraction of fractions of a percent of a metal from a complex mineralogical matrix (i.e., the natural material in which minerals are embedded). Extractive metallurgy proceeds incrementally. Rome was not built in a day, and all metal cannot be extracted in one fell swoop. In consequence, materials are reprocessed in order to remove as much of the pure metal as possible from the natural ore...What is more, valuable metal-bearing and mineral-bearing dusts are often released in processing a particular metal. The mining facility typically recaptures, recycles, and reuses these dusts, frequently in production processes different from the one from which the dusts were originally emitted."

The court then concluded that such materials are not covered by the Act's definition of "solid waste," and therefore cannot be regulated as such:

> RCRA was enacted, as the Congressional objectives and findings make clear, in an effort to help States deal with the ever-increasing problem of solid waste disposal (including recycling) and protecting health

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14/ Reese, R.G., "Silver," chapter in Minerals Yearbook 1984, U.S. Department of the Interior, Bureau of Mines, Washington, D.C., 1985, p. 819.

and the environment by regulating hazardous wastes. To fulfill these purposes, it seems clear that EPA need not regulate "spent" materials that are recycled and reused in an ongoing manufacturing or industrial process. These materials have not yet become part of the waste disposal problem; rather, they are destined for beneficial reuse or recycling in a continuous process by the generating industry itself."

"We are constrained to conclude that, in light of the language and structure of RCRA, the problems animating Congress to enact it, and the relevant portions of the legislative history, Congress clearly and unambiguously expressed its intent that 'solid waste' (and therefore EPA's regulatory authority) be limited to materials that are 'discarded' by virtue of being disposed of, abandoned, or thrown away. While we do not lightly overturn an agency's reading of its own statute, we are persuaded that by regulating in-process secondary materials, EPA has acted in contravention of Congress' intent (slip op. at 18, 34-35, emphasis in original, footnotes omitted).

Accordingly, EPA has no authority to regulate as waste valuable secondary materials that are produced by and reprocessed in Kennecott's copper processing facilities. In what follows, a clear distinction is made between materials that are "discarded" versus those that are legitimate process materials.

The Importance of Water At An Integrated Primary Facility--A Second Key Perspective

Another general point to be made when discussing materials management at an integrated copper-producing facility is the identification of water as a key process stream rather than a waste stream. In addition to the "conventional" uses of water which are common to many industries (e.g. process cooling), the primary copper industry has several important and unique water uses. For example:

(i) Water is an essential element in the copper dump leach and precipitation process. Here water is sprayed on leachable ore (see Photograph 3 and Figure 3) and as it trickles through the material, a mild acidic solution is formed and copper is leached from the material. 10,000-15,000 gpm of this copper--containing material (called a "pregnant liquor") is collected in a series of concrete-lined canals and routed to a precipitation plant (see Photograph 4) using scrap iron as a reagent. The precipitate thus formed contains 80% to 90% copper.[15/] Precipitate copper

15/ For a discussion of the process see SUTULOV, A., Copper Porphyries, Miller Freeman Publications, San Francisco, 1975, pp 129 et seq.

has been an important component of Kennecott's production since 1924 and is planned to account for approximately 7% of Kennecott's copper output in the future. The water is part of a closed loop system and, is recycled, except for evaporation from the storage reservoir and some leakage due to historical practices no longer used. (This leakage is now under study by Kennecott.)

(ii) Water is essential to the froth flotation separation process employed in the beneficiation process (see Photograph 5).

(iii) Water is essential to the fine grinding step in beneficiation.

(iv) Finally, water is used as a "transport medium" to carry tailings from the concentrator to the tailings pond. (In the modernized configuration, water will be used to transport a concentrate slurry from the concentrator to the smelter in place of the present rail haul system.) Here again it is important to recycle as much water as possible and (after treatment if required) many water streams are routed to the tailings pond for recycle.

The entire integrated facility is designed around the concept of maximizing water recycle. For this reason, Kennecott does not agree that its water streams containing contaminants or wastes are waste streams in a RCRA context. Any such streams (e.g., refinery bleed electrolyte or acid plant blowdown) are treated in plants (WWTP) and the purified water is recycled for many process uses. It is legitimate to regard the treatment plant sludges as wastes, but Kennecott maintains that the water itself is a process stream. It is interesting that this argument follows directly from the integrated nature of the facility. As noted, water recycle is critical to Kennecott's operations.

These preliminaries aside, the balance of the discussion examines each of the major stages of copper production.

Mining

Mining consists of drilling and blasting operations to break up the rock/earth matrix followed by segregation and loading of overburden and ore materials. Overburden--the majority of which is leached[16/] is placed on dumps, and ore is sent to the concentrator.

The only wastes generated in the mining step are:

16/ Some overburden is unsuitable for leaching because of the presence of certain impurities or because it is excessively alkaline (carbonate). This material is placed on separate dumps, along with barren rock or material that does not contain enough copper to permit economic recovery.

(i) A minority of the overburden that is unsuitable for leaching is discarded on mine dumps. It is estimated that 25% of the overburden will not be leached, so based upon the flowchart numbers (given in Figure 2), a waste generation rate of approximately 53.7 tons/ton of copper throughput is estimated. This waste would not be classed as hazardous by any applicable test.

(ii) Trucks used to haul overburden generate waste crankcase oil that is taken offsite for treatment. Approximately 65,000 gallons of waste oil are generated annually, so (assuming oil weighs 8 pounds per gallon) a generation rate of 0.0014 tons/ton of copper throughput is appropriate.

(iii) Truck tires are another waste that are presently sent to a truck tire dump. Approximately 336 tires per year are consumed, so (assuming 5800 pounds per tire) a waste generation rate of 0.005 tons/ton copper throughput is appropriate.

(iv) Finally, some sludge is generated as a result of lime treatment in the mine's treatment plant. This is estimated to total 3,660 tons annually, so a waste generation rate of 0.0193 tons/ton of copper is appropriate.

Concentrating (Beneficiation)

As noted, ore beneficiation involves the crushing and grinding of ore followed by froth flotation to separate molybdenite and copper from waste material called tailings.[17/] Figure 6 shows a schematic flowchart of the concentrator. Materials generated in the beneficiation step are:

(i) Tailings, which are slurried to Kennecott's 5600 acre impoundment (Photograph 6) and discarded, are a waste. This is 110 feet high and, over the years, more than 1.3 billion tons of material have been impounded in this area.[18/] Under the new operating plan, tailings from the flotation circuit will flow by gravity through a 48 inch pipeline to the tailings pond located near Magna, Utah. The pipeline is constructed of heavy wall concrete pipe, with bridge crossings and drop box entries being rubber-lined steel pipe. The pipeline has a total length of 70,000 feet and is installed on a continuous 0.8%

17/ For details of froth flotation, see Sutulov, op. cit.

18/ For details see Kennecott Comments, Wastes From The Beneficiation of Metallic Ores, Phosphate Rock, Asbestos, Overburden from Uranium Mining, and Oil Shale, 31 March 1986.

downslope with 33 drop boxes. The total drop in the pipeline system is approximately 1,200 feet. Pipeline flow level measurement at three locations, with data cable connection to the concentrator central control room, is provided. The normal operating condition for the pipeline is transporting approximately 41,000 gpm of tailings at 28% solids. The pipeline capacity ranges from 8,000 to 60,000 gpm of tailings. Historical tailings quantity estimates for the Bingham mine are given in Table 5.

As shown in Table 2, the estimated daily tailings generation rate is (77,000-1844-32.5) or 75,123 tons equivalent to an annual quantity of 27.4 million tons or 144.3 tons/ton of copper produced. Tailings material is basically soils or grandulated waste rock and is non-hazardous in terms of the EP toxicity test. The chemical constituents and their concentrations in tailings are comparable to typical local soils (background).

(ii) Some concentrator "adverse" water (not shown in Figure 6) is sent to a treatment plant which, in turn, generates a sludge. This sludge is removed periodically from the impoundment and returned to the smelter and is not, therefore, a waste material.

The energy requirements for copper production are greatest for the beneficiation steps, so it is appropriate at this juncture to mention the electric power plant that is part of the integrated facility. This power plant consists of two 25-megawatt units, a 50 megawatt unit, and a 75 megawatt unit. Each unit has three coal pulverizers, boiler, turbine generator, electrostatic precipitator, emission stack, transformer(s), controls, and auxiliaries. This plant can burn either coal or natural gas as a fuel--at present it burns 98% coal and 2% natural gas. Coal combustion generates wastes in the form of fly ash and boiler bottom ash, both of which are disposed of on the tailings pond. Based upon an annual coal consumption rate of 200,000 tons per year with an ash content between 8% and 10%, some 18,000 tons per year of waste, equivalent to 0.0947 tons per ton of copper, is generated. This ash is not a hazardous waste.

Smelting

Kennecott operates one of the most modern copper smelting and emission control facilities in North America. The smelter is shown in Photograph 7. During the mid-1970's, over $475 million ($1983) was spent modifying the smelter and making the environmental control systems more efficient.

In brief, the smelting process is as follows. At present, concentrates are moved by rail car to the smelter. In the modernized facility, the concentrate slurry is delivered from the new concentrator at Copperton to the smelter in a 6 inch diameter 17-mile-long pipeline. The concentrates contain about 27.5% copper, 27% iron, 32% sulfur and small amounts of silica and other materials. The concentrate slurry is filtered to a 7% moisture filter cake using plate and frame pressure filters.

Flux, coal, slag concentrate, precipitate copper, and recycled smelter secondaries are received and stored in the covered material handling system.

Copper smelting involves a two-step process. First the copper concentrate, flux and coal mixture is fed into the Noranda reactors using a high-speed belt slinger. The Noranda reactors contain a molten bath of iron-silicate slag and high-grade copper sulfide called matte. Oxygen-enriched air is blown into the bath through steel pipes called tuyeres to oxidize the matte, liberate sulfur dioxide and create turbulence to smelt and digest the 130 tons per hour of feed. Molten slag is skimmed from the furnace into large steel pots and transported by rubber-tired slag carriers to the slag treatment area.

Periodically, molten matte containing approximately 70% copper is tapped from the reactor into steel pots and transported by 65-ton overhead cranes to the copper converters, the second step of copper smelting. Approximately 150 tons of molten matte are accumulated in a converter and then the converter is rotated so oxygen enriched air can be blown into the bath through tuyeres. In the converting process, iron is oxidized to form a slag with silica, and sulfur is generated as sulfur dioxide, leaving an impure copper bath of 99% copper. A converter cycle requires 3 hours of blowing and produces about 110 tons of molten blister copper. Approximately 6 converter charges per day are produced. The blister is transferred to the anode plant for further refining.

Both the Noranda reactors and the Peirce Smith converters produce offgases containing high concentrations of sulfur dioxide. These gases are collected by water-cooled hoods, cooled and cleaned in the complex gas handling system. The cooled gases are treated by two sulfuric acid plants capturing approximately 90% of the input sulfur. The two operating acid plants can process up to 167,000 standard cubic feet per minute SO_2-containing gas to recover the sulfur as a salable sulfuric acid product and minimize emissions of sulfur oxides to the environment. As the combined reactor and converter gases are processed, particulates are removed by cyclone separators, electrostatic precipitators and high energy wet gas scrubbers. Some of the flue dust, rich in copper, is returned to the smelting vessels; the rest is stockpiled for future recycling. (Spent vanadium pentoxide is used in the smelter as a substitute flux.) The gases are then distributed to the acid plants where they are heated and oxidized using vanadium oxide-based catalyst. The resulting sulfur trioxide is absorbed to produce sulfuric acid. Over 98% of the sulfur dioxide in the acid plant feed gas is fixed as acid. The clean tailgas is vented up the 1,200-foot stack. Fugitive emissions from the reactors and converters are collected and also ducted to the 1,200-foot stack.

The acid is stored in large tanks and tested to ensure its high quality. It is then loaded into 100-ton-capacity rail tank cars, owned by Kennecott, and shipped to customers throughout the United States of America.

The blister copper is refined in the anode furnaces to produce 99.6% copper which is then cast into copper anodes weighing 760 pounds.

The slag from the Noranda reactors is cooled, crushed, ground and subjected to froth flotation to recover the copper values. The slag concentrator treats about 3,000 tpd of slag containing 7-12% copper, producing a 0.3% copper tailing and a 40-45% copper concentrate. The copper concentrate is filtered and resmelted in the Noranda reactors.

The anodes are sent to Kennecott's nearby Utah electrolytic refinery to complete the final step in the copper process.

The simplified smelter flowchart is shown in Figure 7. As with other steps in the copper production process, careful attention has been paid to controlling smelter losses. As noted above, flue dust recycle was an early improvement to the process. Slag concentrates are returned to the smelter to minimize copper losses. Finally, numerous secondary materials from the smelter or the refinery are returned to the smelter for processing. Copper recoveries at the smelter average 97% to 98%. Solid waste streams include:

(i) Slag concentrator tailings (non-toxic) which are sent to the tailings pond discussed above. It is estimated that approximately 2.16 tons of tailings are generated per ton of copper produced, an annual quantity of approximately 410,400 tons per year.[19/]

(ii) Smelter adverse water and acid plant blowdown water are sent to a treatment plant. The purified water is returned to the tailings pond for recycle to the concentrator. A sludge from the plant is generated as a waste. At present this sludge is being held in two impoundments while studies are underway to select an appropriate treatment technology. The estimated unit generation rate for this sludge is 0.3868 tons per ton of copper produced, approximately 73,500 tons per year.[20/]

Refining

Refining is the last step in the copper production process and is essential to produce a marketable product. Blister or anode copper, the output of the smelter, cannot be fabricated directly, but must be refined. Two processes, fire refining and electrolytic refining are used, although electrolytic refining accounts for nearly all (94% in 1985 according to the USBM Minerals Yearbook) of domestic primary refining of smelter output. Kennecott's smelter output is purified electrolytically. The process is described below.

Anode copper from the smelter is purified at the copper refinery which has a capacity of 240,000 tons per year of cathode copper. The refining process begins when anodes (anode casting is shown in Photograph 8) weighing 760 pounds and containing 99.6% copper are placed in lined cells containing electrolyte (a mild acid solution). Between each anode, a starter sheet of pure copper is inserted as a cathode to complete the

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19/ Letter from G. Boyce to Ben Haynes, USEPA, 31 July 1987.

20/ Letter from G. Boyce to Ben Haynes, USEPA, 31 July 1987.

electrical circuit. Photograph 9 shows the tankhouse where the process takes place. Low voltage direct current is passed through the cells, causing the impure anode copper to dissolve in the electrolyte and migrate toward the cathode, where the individual ions redeposit as 99.96% pure copper.

New anodes are charged into half of the cells of each section pulled at the conclusion of a 28-day anode cycle. Electrolyte is drained from these

cells, precious metals slimes washed from the anode scrap with high-pressure sprays, slimes washed from the cell bottom for delivery to the precious metals refinery, and the anode scrap removed for recasting. Looped "starter sheets" are placed between the anodes in full-cell loads of 40 by overhead crane to begin the 14-day cathode plating cycle. DC power is supplied by motor generators operated at 16,000 amps. The cells are electrically connected in series with the electrodes in each cell in parallel. Electrolyte flows through the cells at 4-5 GPM in six circulating systems. Electrolyte temperature in the cells is maintained at 135-145°F by steam heating through Karbate heat exchangers. The cells are covered with a membrane to conserve heat.

Glue and thiourea are added to the electrolyte at carefully controlled rates to enhance quality and smoothness of the cathode deposit. Electrolyte purity is maintained by bleeding a portion of the electrolyte for treatment. A portion of the bleed is returned partially decopperized. Electrolyte volume and acid concentration are maintained with condensate and sulfuric acid additions.

After two days of deposition, the cathodes are removed in half-cell loads for straightening in a hydraulic cathode press. The pressing operation improves both current efficiency and cathode quality. Throughout the cathode cycle, short circuits are detected with hand-held gaussmeters and corrective actions taken to eliminate the shorts. At the end of the 14-day cathode cycle, power to the section is interrupted and the cathodes are removed by overhead crane for delivery to the cathode washing machine. The cathodes pass on a conveyor through a 3-stage wash, are stacked, suspension bars ejected, weighed, banded and loaded onto trailers for transport to rail and truck loading docks.

Anode scrap from the electrorefining process is melted by electric arc furnaces and recast into new anodes.

The scrap is melted in a 7 megawatt electric arc furnace which has a holding capacity of 50 tons and a melting capacity of 20 tons/hour. Furnace offgas is sent to a dust collection system for recovery of copper fume and entrained dust.

Pouring rate is controlled by tilting the furnace as required. Copper flows down a launder to a single lip ladle. The casting operator pours one anode at a time to a mold mark. The Walker-type casting wheel contains 14 anode copper molds. Different molds are used to cast 830-lb stripper and 760-lb commercial anodes. A barite slurry is applied as mold wash on each wheel revolution. After pouring, the molds are water-sprayed to solidify the copper anodes. Anodes are removed from the wheel with a manually operated pneumatic hoist and placed into either a rubber-tired anode trailer or a reject rack.

The final copper product at Utah Copper Refinery is electrolytic cathode.

As noted above, a very important aspect of Kennecott's business is the recovery and sale of precious metals from the refinery slimes.

Figure 7 shows a simplified flow diagram of the refinery. Shown also on this figure are some of the return streams of secondary materials which are shunted to either the converter or the reactor at the smelter for further processing.

Streams containing waste materials--the bleed electrolyte and refinery adverse water--are treated in the same plant that treats smelter adverse water and acid plant blowdown water. The sludge generation rate is included in the figure cited earlier.

Summary

Table 8 provides a convenient summary of estimated waste generation rates for this integrated primary copper production facility. In terms of aggregate generation rate, the majority of the wastes are accounted for by non-leachable overburden and by tailings from the ore and slag concentrators.

Kennecott's modern integrated facility is designed to achieve high levels of resource recovery--an objective that is facilitated by integration of all the steps in copper processing.

TABLE 1
MAJOR MILESTONES AT KENNECOTT'S UTAH COPPER FACILITY

1863	-	Official discovery of metals in Bingham Canyon
1903	-	Utah Copper Company formed by Daniel C. Jackling and Enos A. Wall
1904	-	Original 300 TPD gravity pilot plant built at Copperton to demonstrate feasibility of milling, and to prove up crushing equipment capacity
1906	-	First four cubic yard steam shovel in operation
	-	Start-up of American Smelting and Refining Company's (ASARCO) smelter
1908	-	Start-up of the 6,000 TPD gravity concentrator at Magna
1909	-	Completion of the 3000 TPD Boston Consolidated Mining Company gravity concentrator, renamed Arthur Concentrator in 1910
1910	-	Boston Consolidated Mining Company merged with Utah Copper Company
1915	-	Utah Copper Company and ASARCO jointly construct the first acid plant to control sulfur dioxide emissions
1916	-	First leaching operation began with commissioning of precipitation plant
1918-1922	-	Froth flotation replaces gravity separation at both mills
1924	-	Improved precipitation plant erected
1936	-	Kennecott Copper Corporation acquires all property and assets of the Utah Copper Company
	-	Processing facilities for molybdenite separation (Dextrin Process) established at both plants: Utah facility becomes world's second largest producer of molybdenite
1942	-	Central Power Station (CPS) construction commenced to make Utah Copper Company independent of outside sources for electric power. Later renamed Utah Power Plant.
1947	-	Utah Copper Division given its name
1950	-	Start-up of UCD's Garfield Refinery to produce copper cathodes, gold bars, silver bars, platinum and palladium sponge, and commercial grade selenium

1959	-	Kennecott purchases ASARCO's interest in the smelter
1960	-	Major expansion of Utah Power Plant
1966	-	Bonneville Concentrator added to increase capacity from 90,000 TPD to 108,000 TPD
1969	-	Smelter modernized and expanded to treat 2,600 tons of concentrate and precipitate per day
1977	-	Installation of new Noranda smelter and environmental controls to satisfy Clean Air Act mandates at more than $475 million ($1983) cost
1980	-	Beginning of world copper recession
1981	-	Standard Oil acquires Kennecott, including Utah Copper Division
1985	-	Utah Copper Division shutdown
1986	-	New labor agreements ratified in June
	-	First workers recalled to restart existing operations in September
1987	-	Start-up of all Utah Copper operations
1988-2Q	-	Planned start-up of new crushing, conveying, concentrating and filtration plants
1988-4Q	-	All modernized facilities planned to be fully operational

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Sources: Diverse, including

Bray, R.E. and J.C. Wilson, Eds. Guidebook to the Bingham Mining District, Society of Economic Geologists, Bingham Canyon, Utah, 1975.

Parsons, A.B., The Porphyry Coppers, AIME, New York, 1933.

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Kennecott Copper Corporation, The Story of Utah Copper Division, undated.

TABLE 2
RELATIVE IMPORTANCE OF DIFFERENT TYPES OF COPPER DEPOSIT (%)

Type of Deposit	Proportion of Known Reserves USA	All Market Economies
Porphyry	85	76
Strata-bound	13	16
Massive Sulphide	1	3
Other	1	5

Source: Referenced in "The Economics of Copper," Third Edition 1984, p.1, Roskill Information Services, Ltd., London SW9.

TABLE 3
PRINCIPAL COPPER MINERALS AND THEIR OCCURRENCE IN COPPER DEPOSITS

Mineral	Porphyry	Vein and Replacement	Sedimentary	Massive Sulphide	Copper Nickel Sulphide	Native Copper	Secondary Minerals
Native Copper Cu	-	-	x	-	-	x	x
Chalcocite Cu_2S	x	x	x	x	-	-	x
Cavellite CuS	-	-	-	-	-	-	x
Bornite $CuFeS_4$	x	x	x	x	x	-	-
Chalcopyrite $CuFeS_2$	x	x	x	x	x	-	-
Enargite Cu_sAsS_4	x	x	-	x	-	-	-
Cuprite Cu_20	-	-	-	-	-	-	x
Malachite $Cu_2(OH)_2(CO)_3$	-	-	-	-	-	-	x
Tenorite (CuO)	-	-	-	-	-	-	x
Chrysocolla $CuSiO_3$	-	-	-	-	-	-	x
Antlerite Cu, (So) (OH)	-	-	-	-	-	-	x
Chalcanthite CuSO	-	-	-	-	-		x
Azurite $Cu_3(OH)_2(CO_3)_2$	-	-	-	-	-	-	x
Tetrahedrite $Cu_8Sb_2S_7$	-	x	-	x	-	-	-
Tennaite $Cu_8As_2S_7$	-	x	-	x	-	-	-

Sources: Referenced in "The Economics of Copper," Third Edition 1984, p.1, Roskill Information Services, Ltd., London SW9 and The World Copper Industry, "Survey, Analysis, and Outlook," Copper, August 31, 1979, Australian Mineral Economics Pty Ltd., p.13.

FILE: ORE
DISK: KWASTE

TABLE 4. RATIO OF OVERBURDEN TO ORE FOR DOMESTIC COPPER MINES

	SURFACE MINES				UNDERGROUND MINES				ALL MINES			
YEAR	CRUDE ORE (000 ST)	OVERBURDEN (000 ST)	TOTAL (000 ST)	RATIO OVERBURDEN/ ORE	CRUDE ORE (000 ST)	OVERBURDEN (000 ST)	TOTAL (000 ST)	RATIO OVERBURDEN/ ORE	CRUDE ORE (000 ST)	OVERBURDEN (000 ST)	TOTAL (000 ST)	RATIO OVERBURDEN/ ORE
1960	111,395	236,353	347,748	2.12	24,756	1,035	25,791	0.04	136,151	237,388	373,539	1.74
1961	119,017	235,214	354,231	1.98	26,258	684	26,942	0.03	145,275	235,898	381,173	1.62
1962	125,399	242,965	368,364	1.94	26,006	399	26,405	0.02	151,405	243,364	394,769	1.61
1963	123,996	277,394	401,390	2.24	24,516	216	24,732	0.01	148,512	277,610	426,122	1.87
1964	134,579	279,553	414,132	2.08	24,333	330	24,663	0.01	158,912	279,883	438,795	1.76
1965	149,434	286,048	435,482	1.91	26,043	547	26,590	0.02	175,477	286,595	462,072	1.63
1966	158,132	371,210	529,342	2.35	28,718	467	29,185	0.02	186,850	371,677	558,527	1.99
1967	111,969	357,462	469,431	3.19	18,413	79	18,492	0.00	130,382	357,541	487,923	2.74
1968	151,706	486,762	638,468	3.21	22,187	5,872	28,059	0.26	173,893	492,634	666,527	2.83
1969	198,439	621,726	820,165	3.13	27,486	452	27,938	0.02	225,925	622,178	848,103	2.75
1970	232,558	606,321	838,879	2.61	27,390	883	28,273	0.03	259,948	607,204	867,152	2.34
1971	222,450	599,599	822,050	2.70	26,002	915	26,917	0.04	248,453	600,514	848,967	2.42
1972	237,000	683,000	920,000	2.88	34,700	685	35,400	0.02	271,000	684,000	955,000	2.52
1973	286,000	757,000	1,040,000	2.65	34,900	1,270	36,100	0.04	320,000	758,000	1,080,000	2.37
1974	261,000	764,000	1,020,000	2.93	31,900	1,260	33,200	0.04	293,000	765,000	1,060,000	2.61
1975	240,000	689,000	928,000	2.87	29,200	1,360	30,600	0.05	269,000	690,000	959,000	2.57
1976	257,000	686,000	942,000	2.67	25,100	1,360	26,400	0.05	282,000	687,000	969,000	2.44
1977	240,000	594,000	834,000	2.48	25,700	1,500	27,200	0.06	266,000	596,000	861,000	2.24
1978	236,000	368,000	604,000	1.56	26,000	9,980	36,000	0.38	262,000	378,000	640,000	1.44
1979	232,000	548,000	780,000	2.36	44,600	194	44,800	0.00	277,000	548,000	825,000	1.98
1980	219,000	530,000	749,000	2.42	21,100	1,230	22,300	0.06	240,000	531,000	771,000	2.21
1981	273,000	657,000	930,000	2.41	32,600	3,670	36,300	0.11	305,000	661,000	966,000	2.17
1982	172,000	355,000	527,000	2.06	24,300	2,170	26,500	0.09	196,000	357,000	553,000	1.82
1983	175,000	258,000	433,000	1.47	21,400	1	21,400	0.00	196,000	258,000	455,000	1.32
1984*	171,000	312,000	483,000	1.82	22,200	0	22,200	0.00	193,000	312,000	505,000	1.62
1985**												

SOURCE: UNITED STATES BUREAU OF MINES, MINERALS YEARBOOK, VARIOUS ISSUES.

* PER JANICE JOLLY, U.S. BUREAU OF MINES, WASHINGTON, D.C., 14 AUGUST 1987 (202) 634-1053.
**INFORMATION NOT AVAILABLE UNTIL APPROXIMATELY OCTOBER 1987. NO PRELIMINARY INFORMATION AVAILABLE, PER JANICE JOLLY, U.S. BUREAU OF MINES, WASHINGTON, D.C., 14 AUGUST 1987, (202) 634-1053.

FILE: UTAH
DISK: KWASTE

TABLE 5. SALIENT PRODUCTION AND OTHER STATISTICS FOR THE KENNECOTT UTAH COPPER MINE

YEAR	COPPER ORE MINED (000 TONS)	OVERBURDEN REMOVED (000 TONS)	STRIPPING RATIO OVERBURDEN/ ORE	HEADS GRADE % COPPER	CONCENTRATE GRADE % COPPER	RECOVERY %	ESTIMATED CONCENTRATE PRODUCED (TONS)	CONCENTRATE COPPER CONTENT (TONS)	ESTIMATED TAILINGS PRODUCED (000 TONS)	RATIO OF OVERBURDEN PLUS TAILINGS TO COPPER
1905	217	NA	NA	1.98	31.78	65.6	8,865	2,817	208	NA
1906	231	NA	NA	1.96	27.22	59.9	9,962	2,712	221	NA
1907	184	1,450	7.88	1.98	22.75	57.8	9,252	2,105	175	772
1908	2,422	2,083	0.86	1.83	26.59	64.2	106,985	28,447	2,315	155
1909	2,674	3,163	1.18	1.59	25.63	64.1	106,257	27,234	2,568	210
1910	4,340	5,832	1.34	1.54	27.28	66.5	163,151	44,508	4,177	225
1911	4,681	NA	NA	1.51	25.62	69.5	192,117	49,220	4,489	NA
1912	5,315	NA	NA	1.36	20.75	66.3	231,733	48,085	5,083	NA
1913	7,519	NA	NA	1.25	17.31	63.9	346,428	59,967	7,173	NA
1914	6,470	NA	NA	1.43	18.19	66.0	334,734	60,888	6,135	NA
1915	8,494	NA	NA	1.43	19.17	64.1	407,361	78,091	8,087	NA
1916	10,994	NA	NA	1.43	18.71	62.4	525,733	98,365	10,468	NA
1917	12,542	NA	NA	1.34	16.61	61.1	616,657	102,427	11,925	NA
1918	12,161	NA	NA	1.23	16.08	65.1	603,771	97,086	11,557	NA
1919	5,539	NA	NA	1.26	19.86	78.5	275,026	54,620	5,264	NA
1920	5,557	NA	NA	1.16	16.45	81.4	317,998	52,311	5,239	NA
1921	1,221	738	0.60	1.16	21.40	87.8	58,030	12,418	1,163	153
1922	4,364	2,288	0.52	1.26	23.49	80.0	186,970	43,919	4,177	147
1923	11,168	5,228	0.47	1.12	18.63	81.0	544,791	101,495	10,623	156
1924	12,127	12,949	1.07	1.07	18.07	85.9	618,518	111,766	11,508	219
1925	12,538	16,488	1.32	1.02	17.47	87.0	638,158	111,486	11,900	255
1926	13,880	17,932	1.29	1.01	17.07	87.0	714,777	122,012	13,165	255
1927	13,811	15,149	1.10	0.98	25.10	89.1	479,994	120,478	13,331	236
1928	16,558	14,996	0.91	0.99	31.53	85.6	445,716	140,534	16,112	221
1929	17,724	19,821	1.12	0.99	32.06	85.7	471,012	151,006	17,253	246
1930	9,552	13,847	1.45	0.97	32.25	89.0	256,488	82,717	9,296	280
1931	8,148	10,181	1.25	0.96	32.61	91.2	218,891	71,380	7,929	254
1932	3,169	3,651	1.15	0.97	32.40	93.2	88,688	28,735	3,080	234
1933	3,521	3,362	0.95	1.03	33.84	92.8	99,460	33,657	3,422	202
1934	4,087	4,982	1.22	1.02	32.11	94.5	122,937	39,475	3,964	227

TABLE 5(continued). SALIENT PRODUCTION AND OTHER STATISTICS FOR THE KENNECOTT UTAH COPPER MINE

YEAR	COPPER ORE MINED (000 TONS)	OVERBURDEN REMOVED (000 TONS)	STRIPPING RATIO OVERBURDEN/ ORE	HEADS GRADE % COPPER	CONCENTRATE GRADE % COPPER	RECOVERY %	ESTIMATED CONCENTRATE PRODUCED (TONS)	CONCENTRATE COPPER CONTENT (TONS)	ESTIMATED TAILINGS PRODUCED (000 TONS)	RATIO OF OVERBURDEN PLUS TAILINGS TO COPPER
1935	6,530	7,484	1.15	1.00	32.71	89.2	178,535	58,399	6,351	237
1936	13,773	14,859	1.08	0.97	31.50	91.2	386,036	121,601	13,387	232
1937	23,120	28,292	1.22	0.97	34.56	90.9	591,396	204,387	22,529	249
1938	11,705	18,617	1.59	0.94	33.50	91.7	300,855	100,787	11,404	298
1939	19,310	23,111	1.20	0.94	32.42	91.5	511,520	165,835	18,798	253
1940	25,951	30,884	1.19	0.97	33.31	89.2	676,466	225,331	25,275	249
1941	30,090	38,380	1.28	0.98	33.52	88.8	785,044	263,147	29,305	257
1942	33,093	39,716	1.20	0.97	32.88	90.4	885,977	291,309	32,207	247
1943	35,376	41,308	1.17	0.97	31.74	89.9	975,468	309,614	34,401	245
1944	29,274	32,962	1.13	0.98	32.84	91.4	800,212	262,790	28,474	234
1945	23,361	29,003	1.24	0.99	31.40	92.7	680,007	213,522	22,681	242
1946	11,831	13,777	1.16	0.98	32.96	92.0	322,861	106,415	11,508	238
1947	28,539	34,359	1.20	0.97	32.83	92.8	780,851	256,353	27,758	242
1948	24,454	33,480	1.37	0.97	32.93	92.9	670,109	220,667	23,784	260
1949	20,992	26,582	1.27	0.98	33.11	92.9	578,150	191,425	20,414	246
1950	31,038	46,552	1.50	0.96	32.48	92.5	846,019	274,787	30,192	279
1951	30,445	46,551	1.53	0.96	31.89	92.4	843,436	268,972	29,602	283
1952	32,036	46,911	1.46	0.94	31.04	91.8	894,740	277,727	31,141	281
1953	29,922	49,292	1.65	0.93	30.90	92.8	839,941	259,542	29,082	302
1954	24,079	35,856	1.49	0.93	29.90	92.2	687,678	205,616	23,391	288
1955	27,741	46,000	1.66	0.89	30.04	92.1	754,302	226,592	26,987	322
1956	32,321	63,676	1.97	0.83	29.13	91.8	843,504	245,713	31,477	387
1957	30,919	67,089	2.17	0.82	30.77	91.2	754,902	232,283	30,164	419
1958	24,087	41,094	1.71	0.83	30.42	91.7	599,299	182,307	23,488	354
1959	19,673	50,928	2.59	0.81	30.98	92.1	475,498	147,309	19,198	476
1960	28,060	59,537	2.12	0.81	30.44	92.1	688,381	209,543	27,372	415
1961	27,839	71,108	2.55	0.81	29.42	91.2	700,899	206,205	27,138	476
1962	29,175	74,314	2.55	0.77	27.86	90.4	727,339	202,637	28,448	507
1963	26,235	71,669	2.73	0.78	27.85	89.8	656,110	182,727	25,579	532
1964	24,456	57,497	2.35	0.79	27.07	90.5	645,122	174,635	23,811	466
1965	32,089	84,116	2.62	0.80	28.70	89.7	800,144	229,641	31,289	503
1966	33,478	66,304	1.98	0.74	27.56	89.1	796,663	219,560	32,681	451
1967	20,790	34,147	1.64	0.73	27.38	89.3	497,040	136,089	20,293	400
1968	28,344	64,487	2.28	0.70	25.91	88.5	676,081	175,172	27,668	526
1969	38,650	86,060	2.23	0.70	26.97	89.2	893,443	240,962	37,757	514

TABLE 5(continued). SALIENT PRODUCTION AND OTHER STATISTICS FOR THE KENNECOTT UTAH COPPER MINE

YEAR	COPPER ORE MINED (000 TONS)	OVERBURDEN REMOVED (000 TONS)	STRIPPING RATIO OVERBURDEN/ ORE	HEADS GRADE % COPPER	CONCENTRATE GRADE % COPPER	RECOVERY %	ESTIMATED CONCENTRATE PRODUCED (TONS)	CONCENTRATE COPPER CONTENT (TONS)	ESTIMATED TAILINGS PRODUCED (000 TONS)	RATIO OF OVERBURDEN PLUS TAILINGS TO COPPER
1970	40,148	96,274	2.40	0.68	27.11	89.9	904,838	245,302	39,243	552
1971	35,008	83,884	2.40	0.69	27.22	88.0	783,628	213,303	34,224	554
1972	34,952	88,555	2.53	0.68	27.06	89.1	778,694	210,715	34,173	582
1973	38,268	97,399	2.55	0.65	26.37	86.4	817,830	215,662	37,450	625
1974	35,277	105,134	2.98	0.64	26.08	86.9	746,754	194,753	34,530	717
1975	27,318	96,862	3.55	0.61	25.19	87.2	579,998	146,102	26,738	846
1976	29,567	112,149	3.79	0.62	24.07	86.2	656,577	158,038	28,910	893
1977	32,571	112,693	3.46	0.62	25.30	88.0	699,280	176,918	31,872	817
1978	35,938	115,004	3.20	0.60	26.00	88.4	732,936	190,563	35,205	788
1979	37,804	123,182	3.26	0.59	25.87	88.1	754,055	195,074	37,050	821
1980	31,579	99,679	3.16	0.58	25.59	86.9	616,603	157,789	30,962	828
1981	39,023	133,805	3.43	0.58	26.21	87.7	759,571	199,083	38,263	864
1982	36,878	117,648	3.19	0.62	26.11	83.8	789,371	193,050	36,139	797
1983	33,310	89,479	2.69	0.63	24.89	83.0	694,870	172,953	32,615	706
1984	21,964	33,064	1.51	0.66	25.82	85.2	480,402	124,040	21,484	440

SOURCES: ARRINGTON, L.J., AND HANSEN, G.B., "THE RICHEST HOLE ON EARTH--A HISTORY OF THE BINGHAM COPPER MINE", UTAH STATE UNIVERSITY PRESS, LOGAN, UTAH, OCT. 1963, AND INTERNAL KENNECOTT DATA.

TABLE 6A
U.S. COPPER BY-PRODUCT AND CO-PRODUCT RELATIONSHIPS IN 1978

Product	Unit	Quantity	Percent of Total Output
Arsenic	Metric Tons	W	W
Rhenium	Metric tons	W	100.0
Selenium	Metric tons	231	100.0
Palladium	1,000 tray ounces	7	100.0
Tellurium	Metric tons	W	100.0
Silver	1,000 tray ounces	12,501	31.7
Platinum	1,000 tray ounces	1	100.0
Molybdenum	Metric tons	18,992	31.8
Gold	1,000 tray ounces	367	36.7
Nickel	Metric tons	W	W
Sulfur	Metric tons	819,757	7.3
Zinc	Metric tons	4,042	1.3
Iron	Metric tons	W	W
Lead	Metric tons	325	1
Uranium	Metric tons	W	W
Copper	Metric tons	1,340,432	98.8

W = Withheld by USBM to avoid disclosing company proprietary data;
1 = Less than 1/2 unit.
Source: U.S. Bureau of Mines

TABLE 6B
U.S. COPPER BY-PRODUCT AND CO-PRODUCT RELATIONSHIPS IN 1982

Co-product and/or By-product	Unit	Quantity	Percent of Total Output
Arsenic	Metric Tons	W	100.0
Rhenium	Metric tons	W	100.0
Selenium	Metric tons	243	100.0
Palladium	1,000 tray ounces	7	100.0
Tellurium	Metric tons	W	100.0
Silver	1,000 tray ounces	9,566	23.8
Platinum	1,000 tray ounces	1	100.0
Molybdenum	Metric tons	12,527	35.5
Gold	1,000 tray ounces	235	16.0
Nickel	Metric tons	W	W
Sulfur	Metric tons	614,754	6.3
Zinc	Metric tons	W	W
Iron	Metric tons	W	W
Lead	Metric tons	191	1
Copper	Metric tons	1,114,901	97.2

W = Withheld by USBM to avoid disclosing company proprietary data;
1 = Less than 0.1%.
Source: U.S. Bureau of Mines

FILE: WASTE
DISK: KWASTE

TABLE 7. WASTE GENERATION RATES AT THE KENNECOTT INTEGRATED COPPER FACILITY

ANNUAL PRODUCTION ON QUANTITY: 190,000 TONS PER YEAR COPPER (PROPOSED NEW MINING PLAN)

STAGE OF PRODUCTION	WASTE DESCRIPTION	ANNUAL QUANTITY GENERATED	UNITS	CONVERSION FACTOR UNITS/TON	ESTIMATED WASTE GENERATION RATE TONS/TON COPPER	ESTIMATED WASTE GENERATION RATE TONS/YEAR	REMARKS
MINING	WASTE OVERBURDEN	10,220,000	TONS	1.000	53.7895	10,220,000	ESTIMATE IS ONLY APPROXIMATE
	WASTE OIL	65,000	GALLONS	0.004	0.0014	260	
	WASTE TIRES	950	TONS	1.000	0.0050	950	BASED ON 336 TIRES @ 5800 LBS
	WWTP SLUDGE	3,660	TONS	1.000	0.0193	3,660	
BENEFICIATION	TAILINGS	27,420,078	TONS	1.000	144.3162	27,420,078	EST. BASED ON NEW MINING PLAN
POWER GENERATION	ASH (FLY AND BOTTOM)	18,000	TONS	1.000	0.0947	18,000	BASED UPON 200,000 TONS COAL
SMELTING	SLAG TAILINGS	410,400	TONS	1.000	2.1600	410,400	SENT TO TAILINGS POND
	WWTP SLUDGE	73,492	TONS	1.000	0.3868	73,492	INCLUDES SLUDGE FROM REFINERY
REFINING	WWTP SLUDGE	0	TONS	1.000	0.0000	0	INCLUDED IN SMELTER ESTIMATE.
TOTAL	ALL				200.7728	38,146,840	TOTAL OF ALL WASTES

SOURCES: DETAILLED IN TEXT

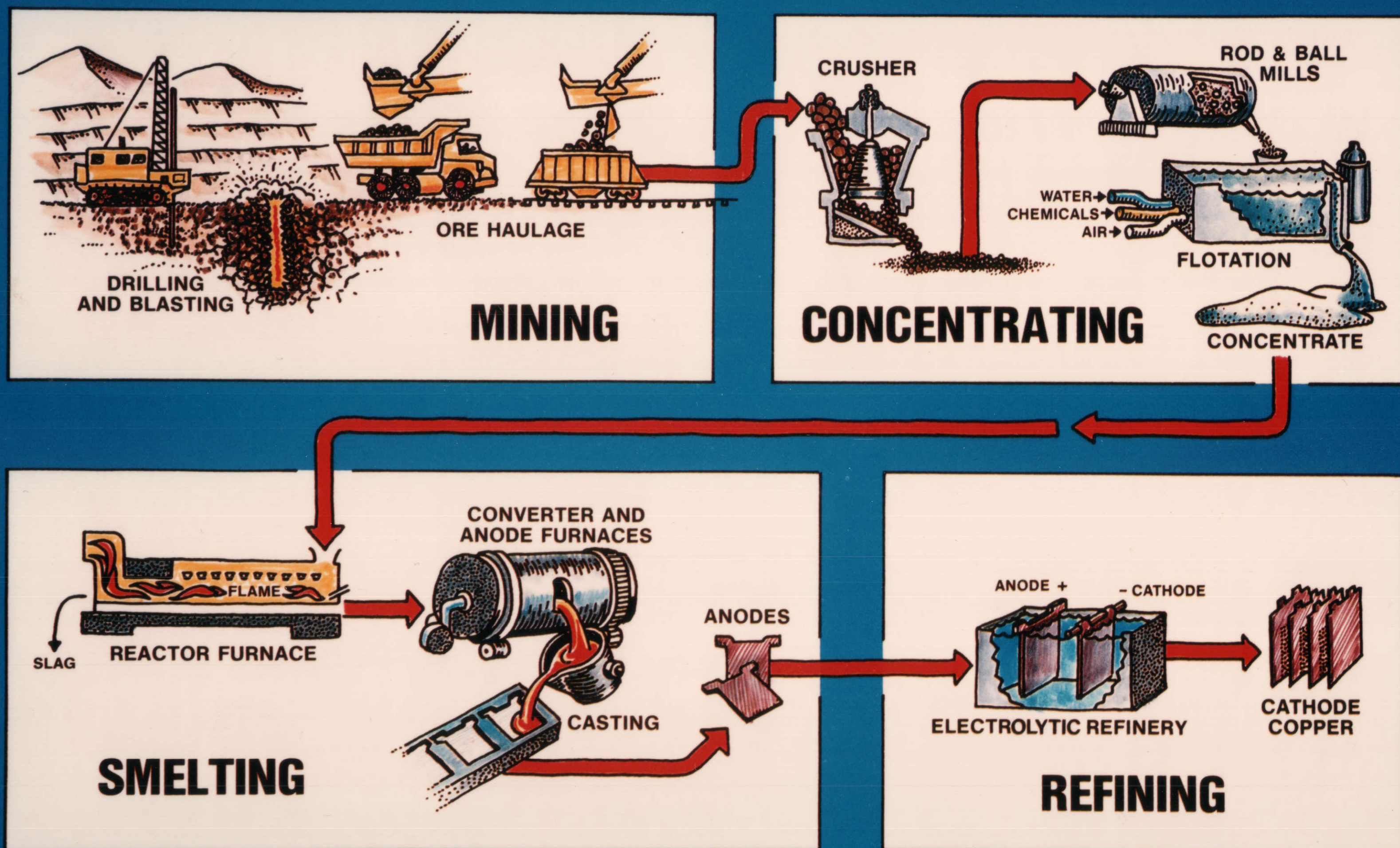
FILE: WASTE
DISK: KWASTE

FIGURE 1

- o Primary copper is made by a four step process:

Mining:	Removing overburden to expose ore; removing ore to concentrator
Concentrating:	Grinding and separating ore from waste using froth flotation to produce a concentrate
Smelting:	Removing sulfur, iron and other impurities by pyrometallurgical methods to produce a 98% pure anode
Refining:	Producing 99.9% pure copper cathodes by electrolytic means

- o This flow chart is highly simplified, and numerous recycle streams are not shown.

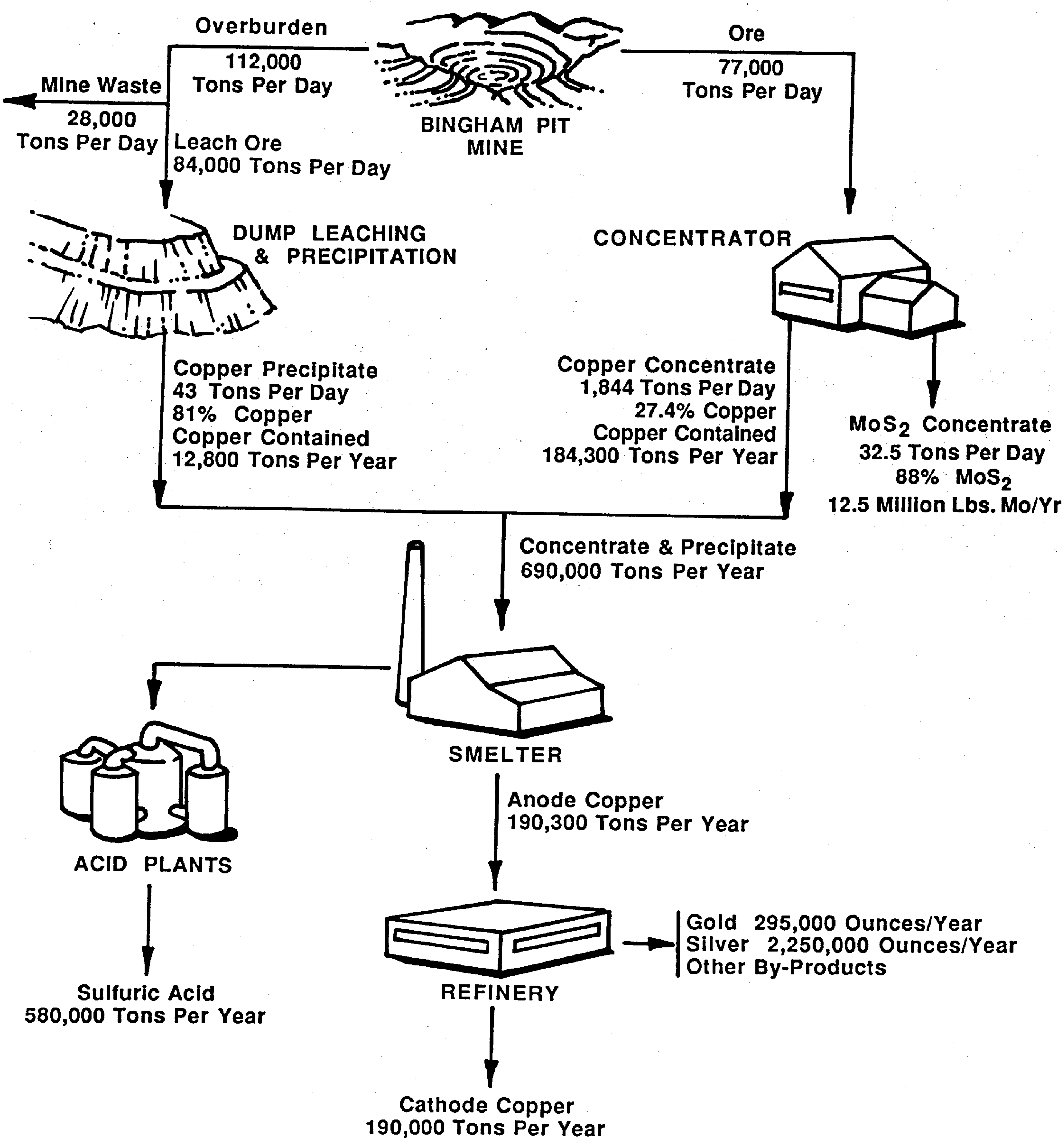


COPPER PRODUCTION CYCLE

FIGURE 1

FIGURE 2

- This diagram shows a flow sheet for Kennecott's integrated facility that includes plants for all steps in the copper production cycle.
- The mine has been in operation since 1905, is the largest man-made excavation in the world and produces nearly 200,000 tons per year of copper.
- The facility produces several by-products as well as copper, including molybdenite, gold, silver, platinum, selenium and other materials.
- Mine overburden is segregated into mine waste and leach ore on a 25%/75% split.



UTAH COPPER DIVISION

PRODUCTION DIAGRAM AFTER MODERNIZATION

FIGURE 2

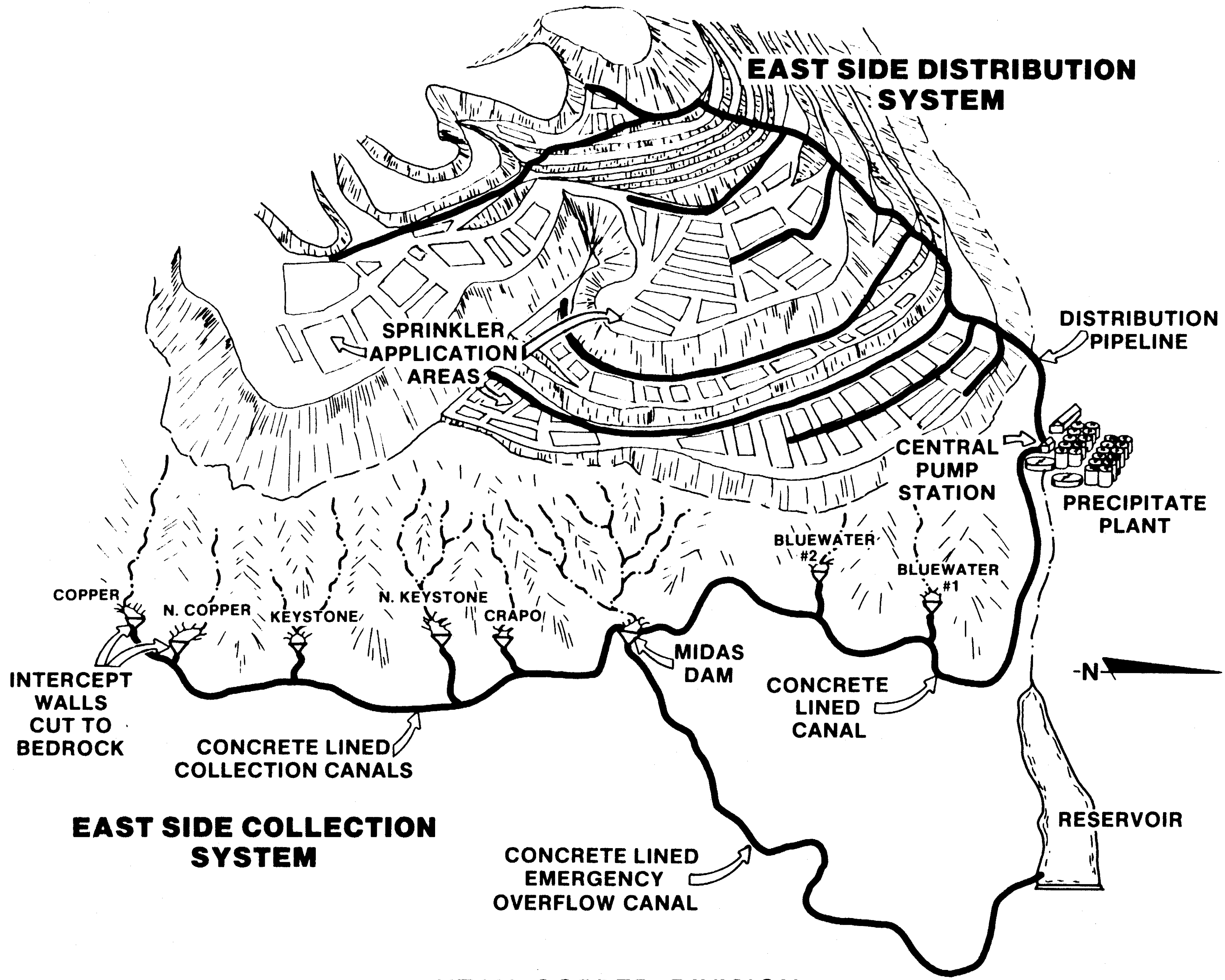
FIGURE 3

- The Utah facility also leaches copper from low grade ores by trickling water through the leach ore, collecting the "pregnant liquor," and precipitating out the contained copper.

- This leach system now produces 7% of the total output of copper.

- The liquor collection facility was designed and installed using "State-of-the-art" engineering techniques including concrete cut-off walls, clay liners, bedrock keys.

- Groundwater problems currently under study involve historic processes or practices no longer used by the mining industry.



UTAH COPPER DIVISION
LEACH SYSTEM

FIGURE 3

FIGURE 4

- This shows a time trend of copper ore as mined at Bingham. It parallels nationwide trends.
- Presently, ore grades of about 0.6% are mined, equivalent to a yield of 12 <u>pounds</u> of copper per ton of ore.
- Unlike industrial operations, the mining industry generates large quantities of low-toxicity waste.
- The economics of resource recovery are a strong incentive to minimize any yield losses.

DECLINING ORE GRADES AT BINGHAM CANYON MINE

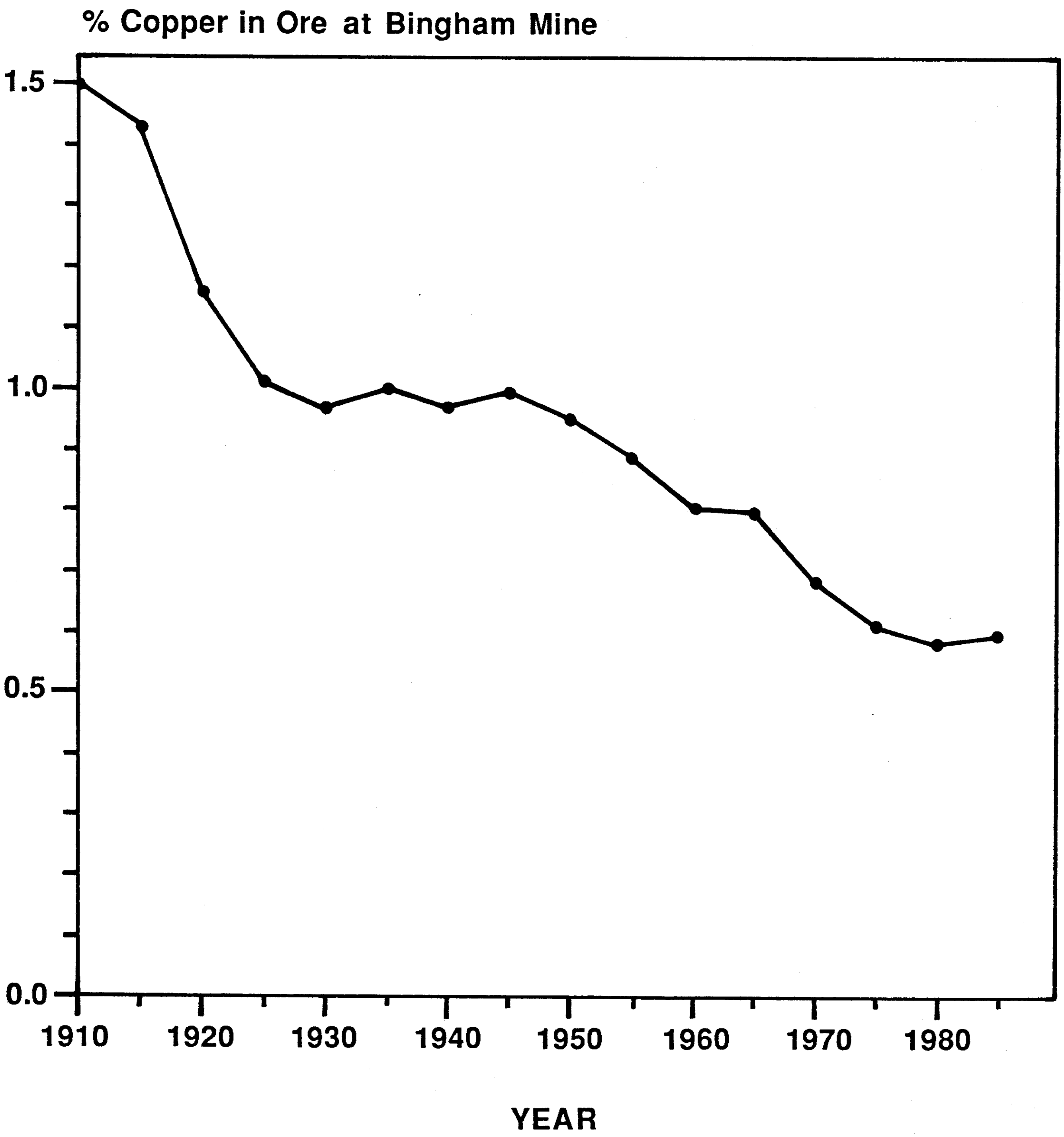


FIGURE 4

FIGURE 5

- This chart shows the ratio of overburden and tailings to copper produced at the Bingham mine.

- Because of declining ore grades, this ratio is increasing over the long term. (The ratio dropped in 1984 as a result of changes in operation during reduced production.)

- As technology improves, the volumes of lower grade material which can be mined at a profit will increase and therefore so will the volume of total material mined.

THE COMBINED EFFECTS OF INCREASING STRIPPING RATIOS, DECLINING ORE GRADES, AND INCREASING RECOVERY: LARGE AND INCREASING WASTE VOLUMES

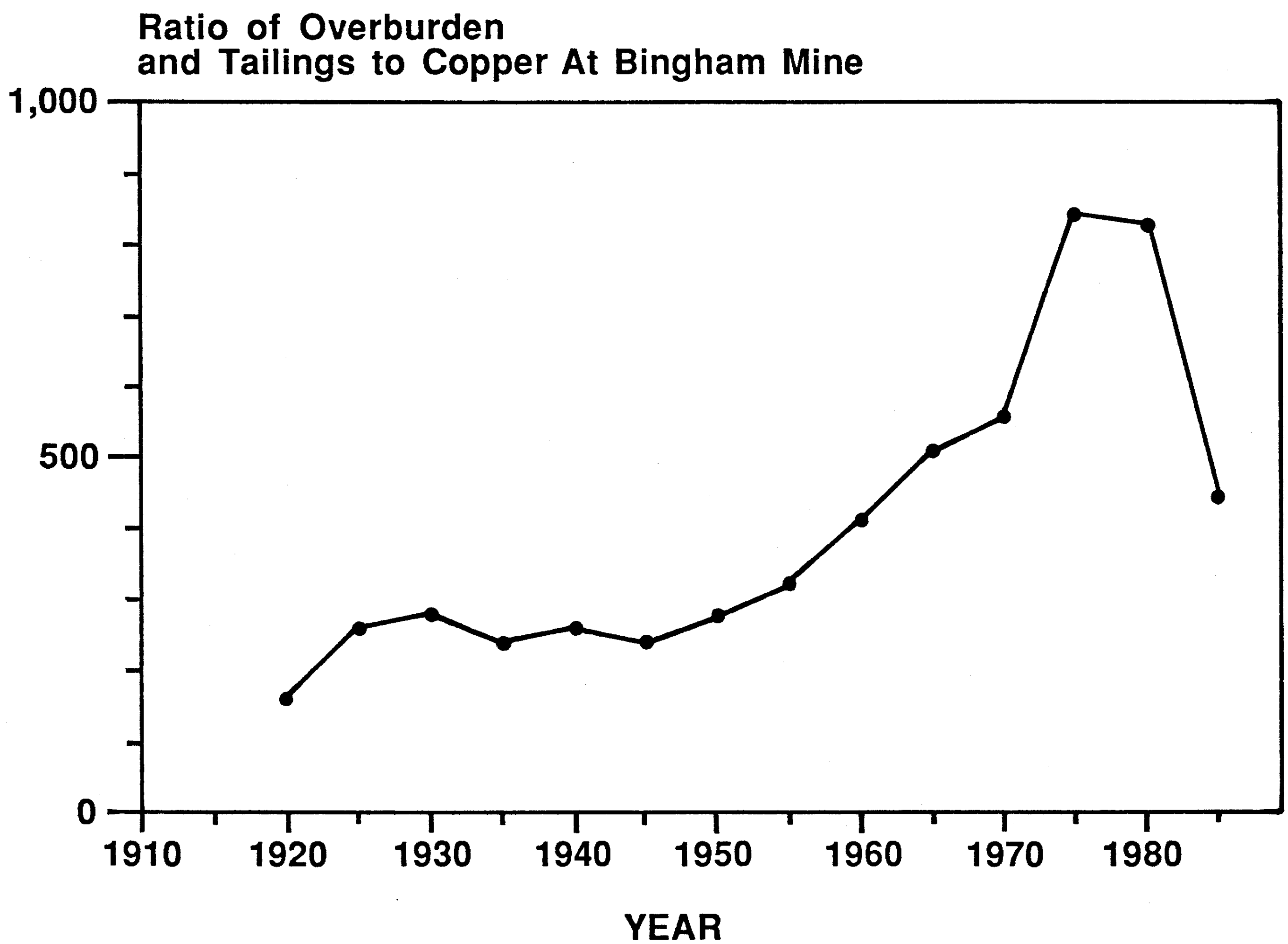
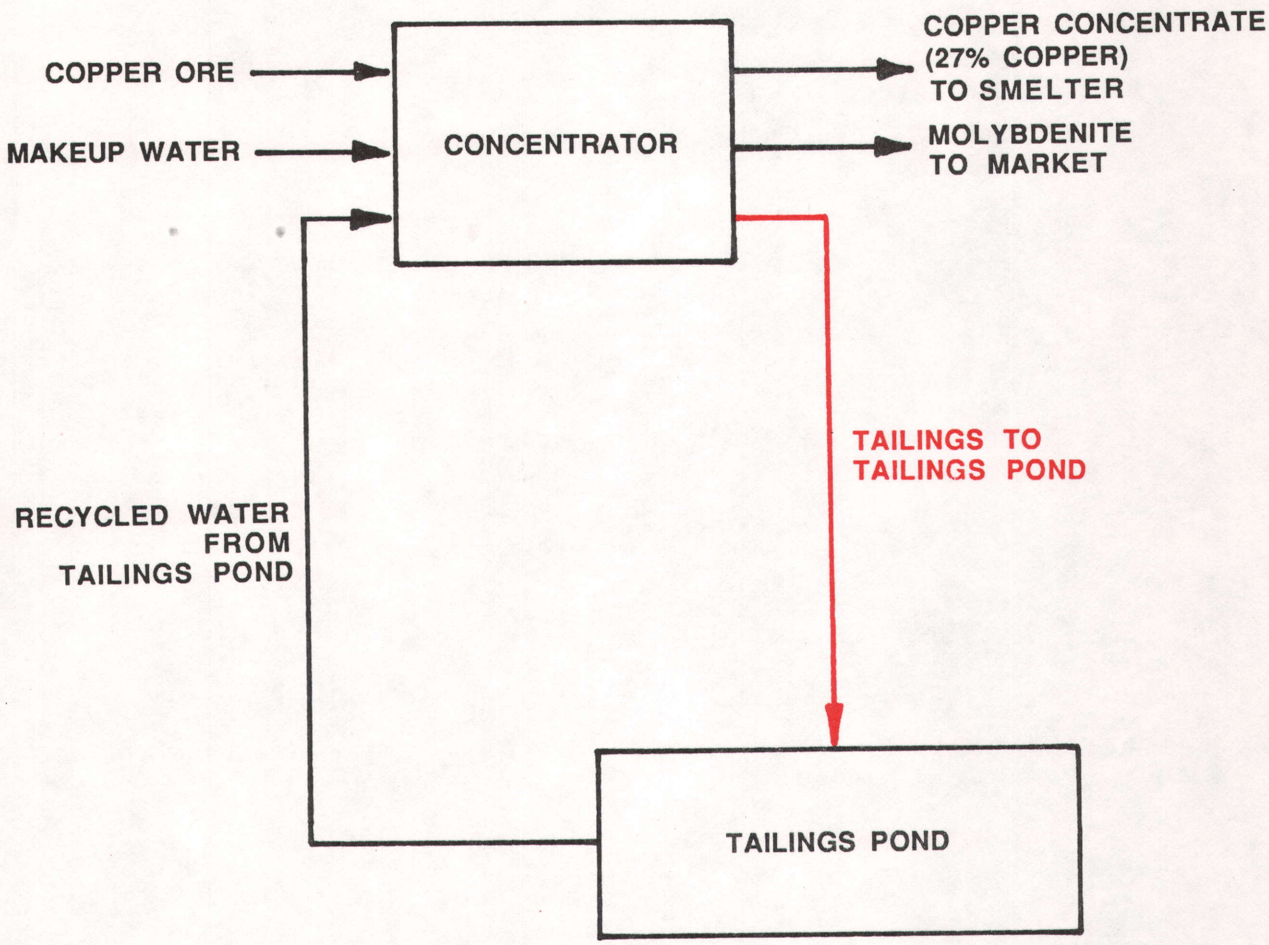


FIGURE 5

FIGURE 6

- The concentrator produces a 27% copper concentrate from the mine ore.
- Tailings--a non-hazardous waste stream--are discharged to the 5600 acre tailings pond.
- All water practical is recycled back to the concentrator for process purposes.
- Make up water comes from various sources:
  - deep wells
  - surface streams
  - treated refinery and smelting adverse waters
  - treated acid plant blowdown water

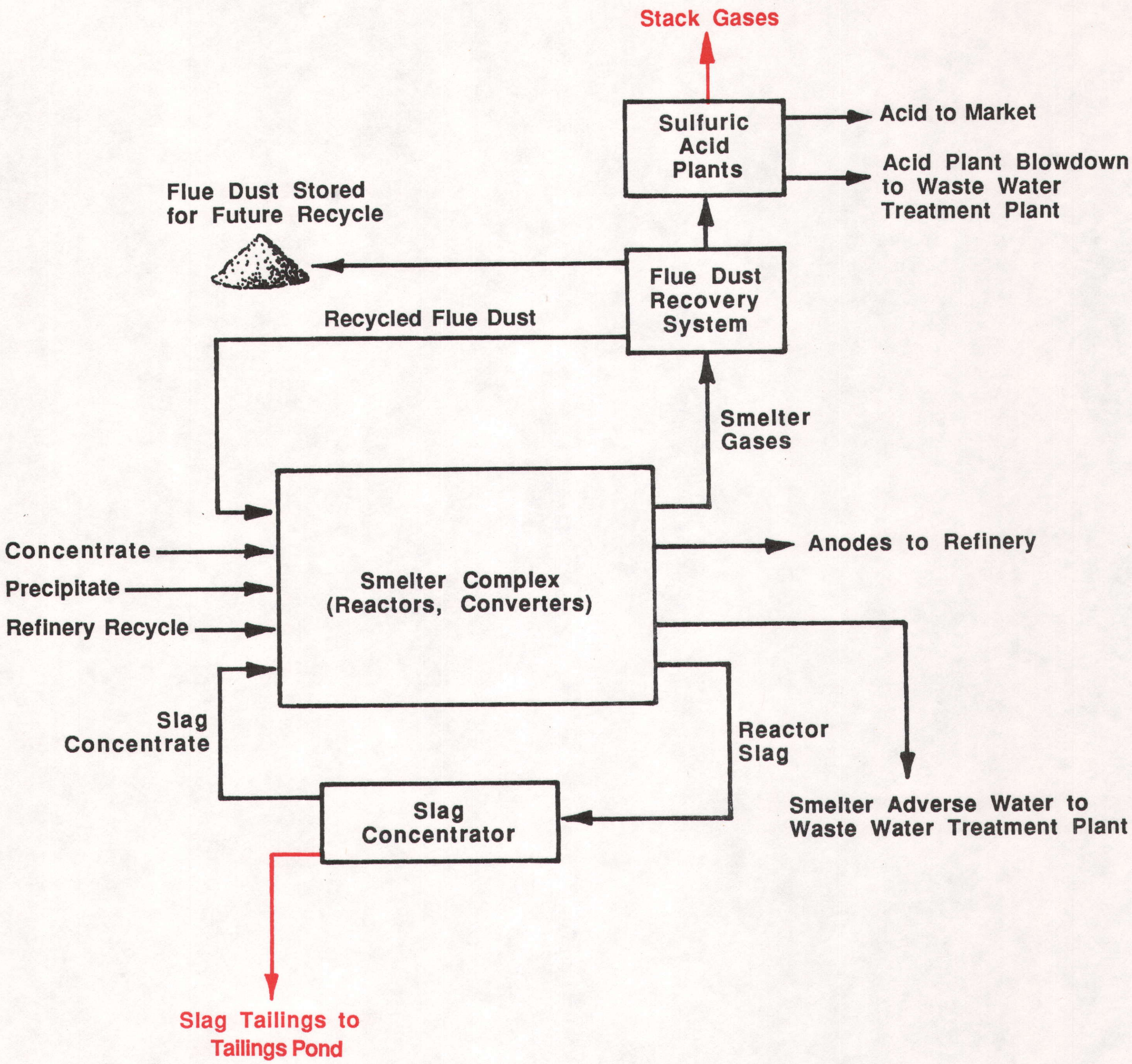


SIMPLIFIED FLOW DIAGRAM OF UTAH CONCENTRATOR

FIGURE 6

FIGURE 7

- The smelter treats concentrates, precipitate copper, and secondary materials from the refining process by pyrometallurgical means to produce copper anodes.
- Numerous recycle loops are found here--of which only a sample are shown.
- Reactor slag, containing 7% copper is concentrated and the slag tailings are discarded.
- Adverse water and acid plant blowdown water are sent to a waste water treatment plant.
- Sulfuric acid is produced by the acid plants, whose purpose is to control emissions of sulfur dioxide to the air.



SIMPLIFIED FLOW DIAGRAM OF UTAH SMELTER

FIGURE 7

FIGURE 8

- The refinery produces numerous products and secondary materials which are recycled. This chart is also simplified.
- Many of the secondary materials produced at the refinery have been incorrectly characterized as wastes. A court ruling now makes this quite clear.
- Waste water treatment plant sludge formed from treating refinery spent electrolyte is the only refinery waste.

RECYCLE STREAMS AT THE UTAH REFINERY

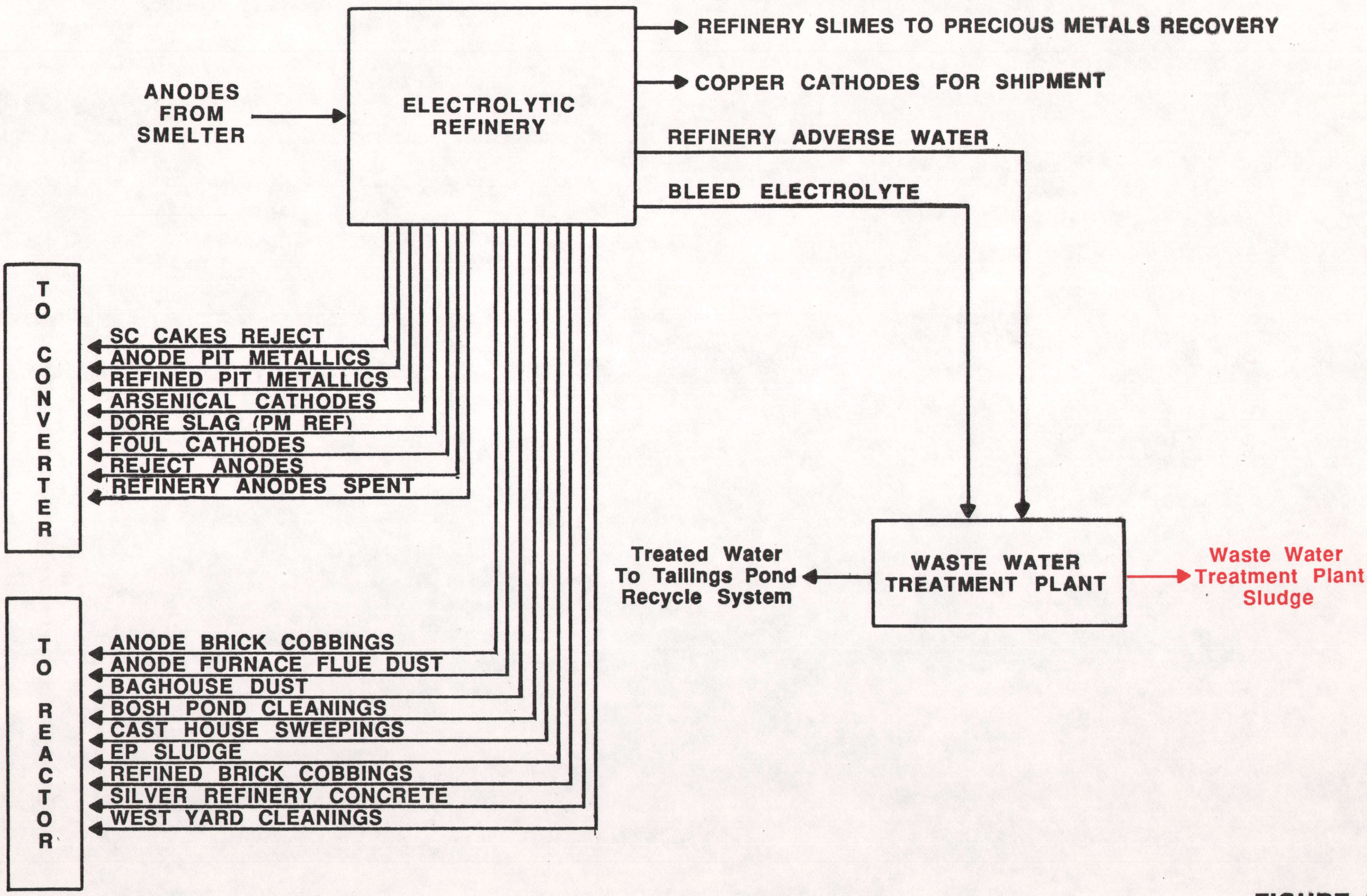


FIGURE 8

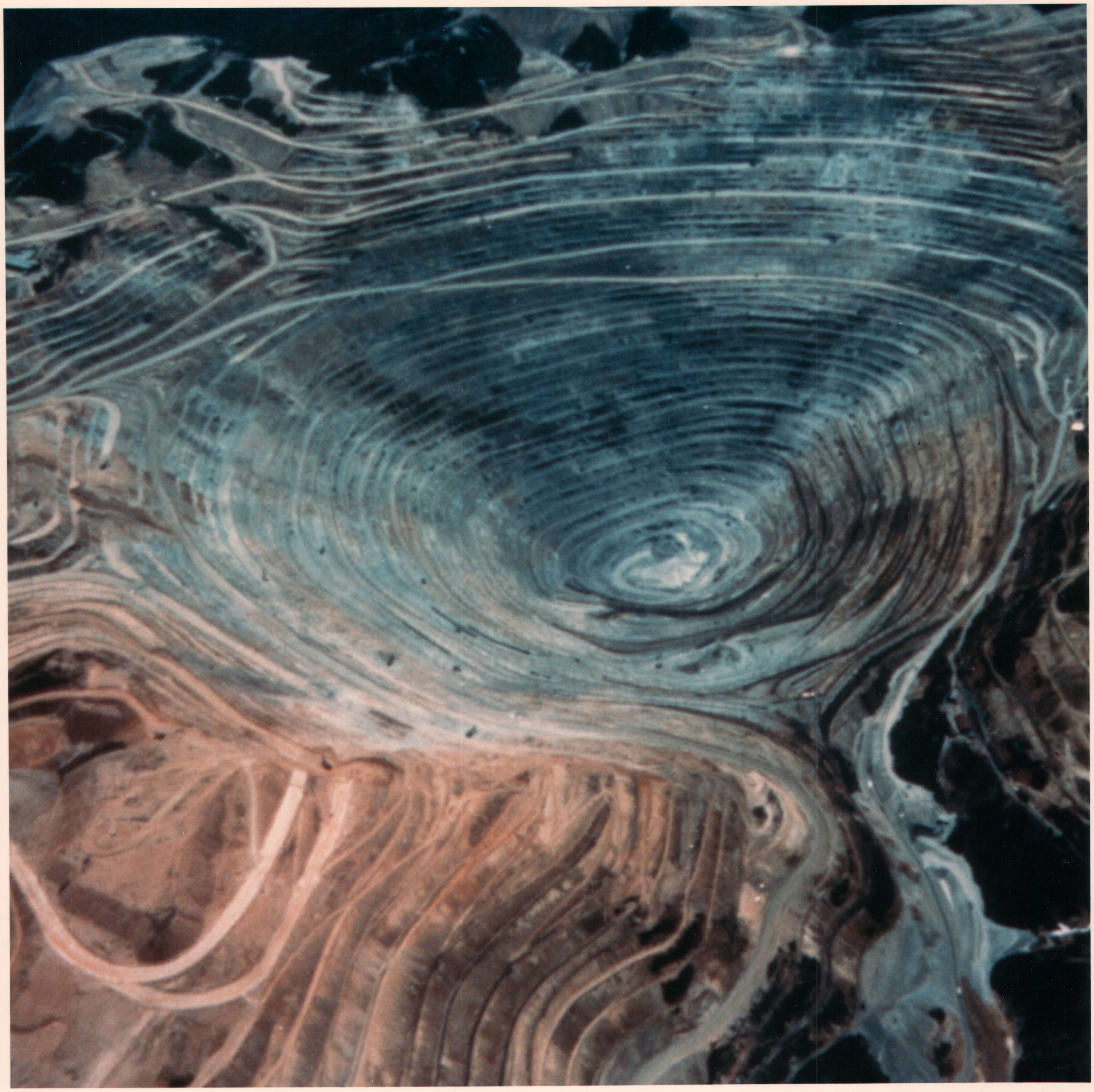


Photo 1 - Bingham Canyon Mine

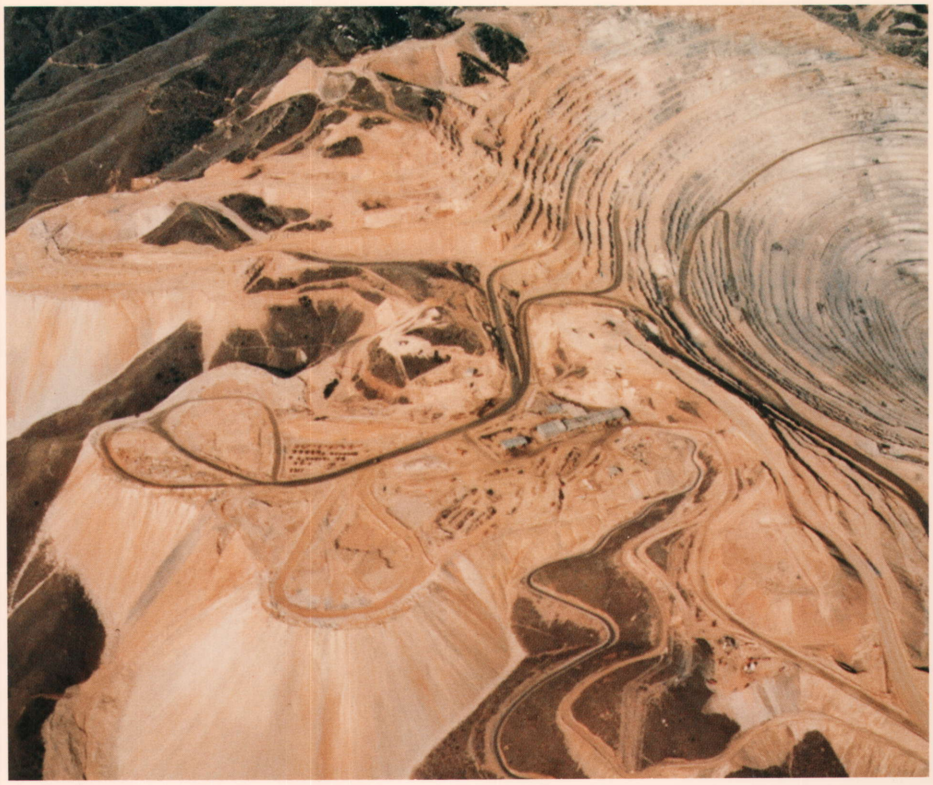


Photo 2 - Partial View - Mine Waste Dumps

Photo 3 - Partial View - Mine Leach Dumps

Photo 4 - Precipitation Plant

Photo 5 - Concentrator Facility Under Construction

Photo 6 - 5,000-Acre Tailings Pond

Photo 7 - Smelter Facility

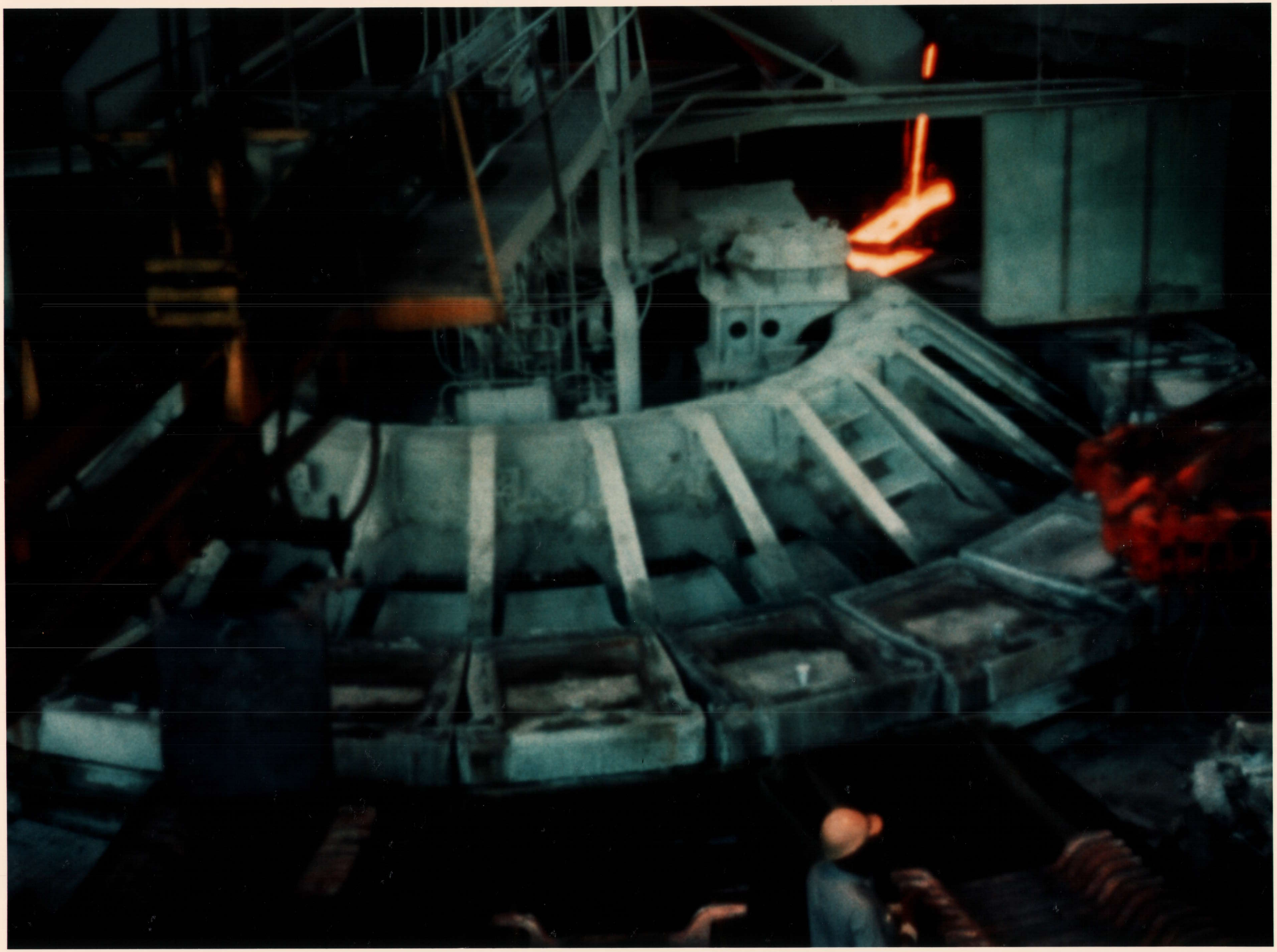


Photo 8 - Smelter Anode Casting Section

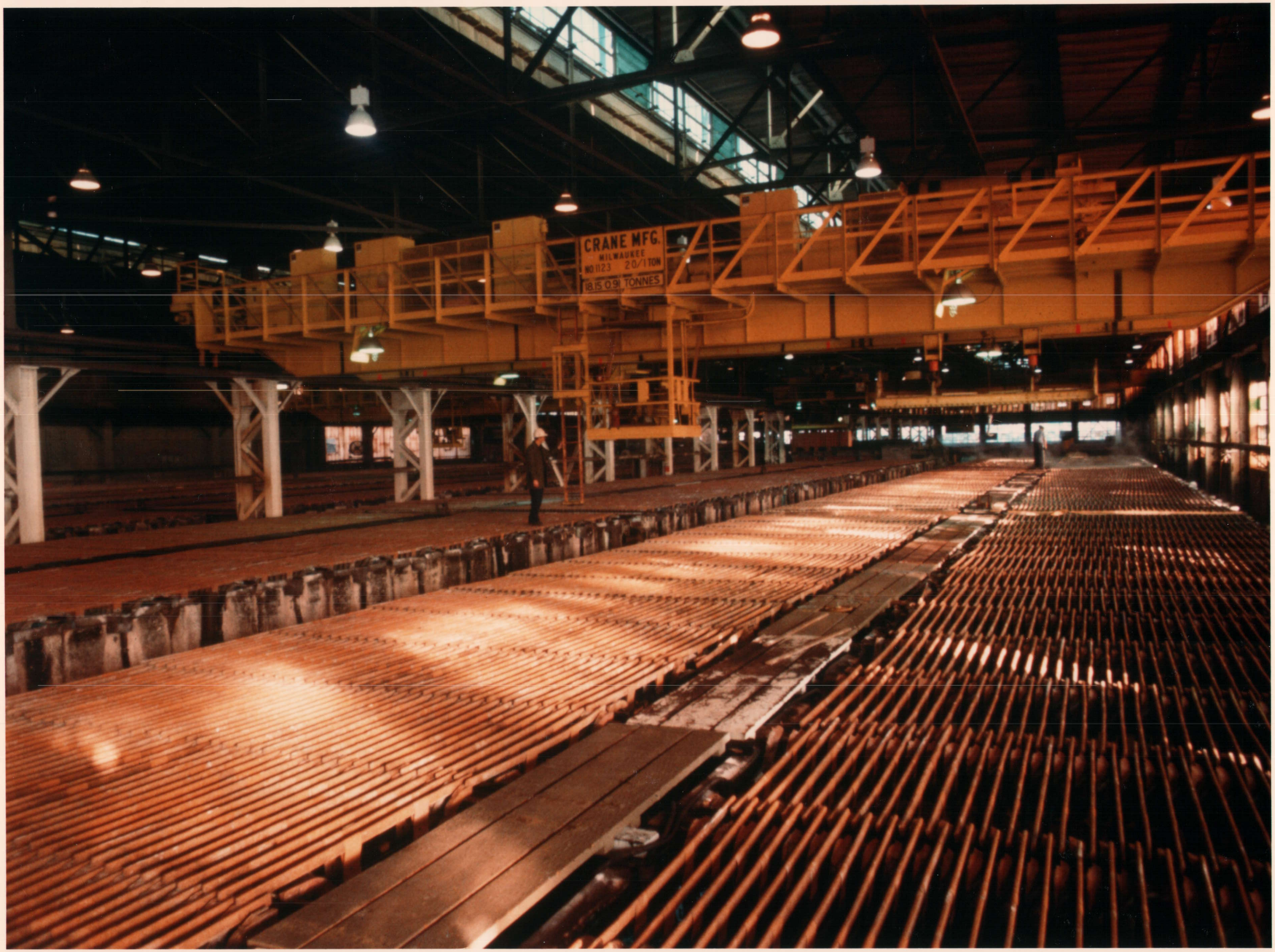


Photo 9 - Refinery Tank House